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Attention and Situational Awareness in First Responder Operations

Guidance for the Design and Use of Wearable and Mobile Technologies

January 2016

TF Sanquist
MP Baucum
BR Brisbois

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Summary

Concepts for Next Generation First Responders (NGFR) emphasize the capabilities of enhanced access to various kinds of information, whether through wearable technologies or other forms of display such as incident command common operating pictures. A critical issue in developing and deploying wearables and other forms of data augmentation such as in-vehicle displays is the extent to which responders can make use of additional information while performing their primary tasks effectively. Humans have limited capacities for processing information, which are relatively fixed and will not change despite a greater availability of inputs. This report reviews research in the areas of attention and situational awareness as it pertains to first responders' safe and effective job performance.

The research reviewed supports a human-centered view of situational awareness, based on the limited capacities of people for processing information, which is determined largely on the basis of what they pay attention to at any particular moment. Attention can be consciously directed but also overridden by reflexive orienting mechanisms, referred to as hard-wiring. Thus, ever-increasing levels of data that are streamed to people can have a beneficial impact in terms of speed and convenience of access, but also a detrimental impact on situational awareness. This is seen in social situations, driving, providing medical care, and even walking. First responders are subject to the same capacity limitations as civilian citizens – while they do develop strategies and experience for what to pay attention to and when, it is clear from studies of emergency response driving and accidents that distraction and performance degradation do occur as a result of technology.

The research needs of the NGFR program for situational-awareness design guidance and parameters are quite similar to the recommendations provided 20 years ago to the Army by the National Research Council (1997). PNNL has adapted these recommendations to address what we believe to be the most pressing issues for designing attention-sensitive technologies for first responders. The research recommendations are:

1. Undertake research concerning the interaction between design attributes, human factors, and effective performance in first responder jobs and tasks.
2. Develop catalogs of critical information needs for specific first responder tasks that can be provided by NGFR wearable and mobile technologies.
3. Develop realistic design concepts that incorporate near-term connectivity infrastructure (cellular, wireless, public safety radio, etc.) to develop field-testable prototype devices.
4. Determine threshold values for visual clutter in head-mounted displays and other wearables that incorporate displays, and design approaches to attention management such as de-cluttering.
5. Conduct research to evaluate the impact of high workload in emergencies upon attentional focus of responders – what do they pay attention to now, and how will additional data streams affect this?
6. Establish field research settings in which first responder situational awareness can be studied in a real-world context.

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Contents

Figures

Tables

1.0 Introduction

Concepts for Next Generation First Responders (NGFR) emphasize the capabilities of enhanced access to various kinds of information, whether through wearable technologies or other forms of display such as incident command common operating pictures. The ability to access (for example) building floor plans, location of team members, critical supply levels, etc., in real time, is considered important for improving operational capability and responder safety (Figure 1). Advances in sensors, data processing and storage, and wireless communication provide the input stream and infrastructure to support responder information augmentation. In a recent technology survey, Upton and Stein (2015) list 10 head-mounted displays (HMD) and six wearable communication devices currently in development or production that could have use for first responders.

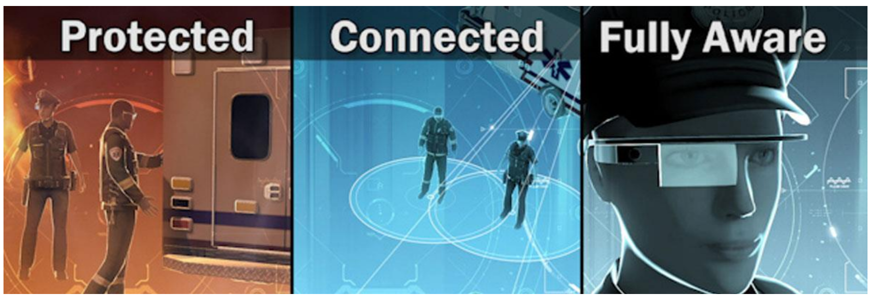

Figure 1. DHS Next Generation First Responder Concept.
(Source: DHS, 2015)

Wearable technologies proposed or developed for first responders include wearable computing for crime scene investigation (Baber, Smith, Cross, Zasikowski & Hunter, 2005), HMDs for firefighters (Wilson et al., 2005; Wilson & Wright, 2009), and an HMD specifically for paramedic use (Sasse & Johnson, 1999). A simulation study by Wilson and Wright (2009) illustrated a beneficial effect of an HMD for indoor navigation. Thus, at least from a production standpoint, the application of wearable technology to emergency response shows promise, yet research indicates no systems have reached the point of maturity where operational evaluations can be performed.

A critical issue in developing and deploying wearables and other forms of data augmentation such as in-vehicle displays is the extent to which responders can make use of additional information while continuing to perform their primary tasks effectively. Humans have limited capacities for processing information, which are relatively fixed and will not change despite a greater availability of inputs. Further, evidence has accrued from a variety of sources to indicate that wearable and mobile technologies can lead to distraction and accidents in both the general population and emergency responders (Strayer, 2015; Yager et al., 2015). Concerns about safety have prompted many states to prohibit the use of hand-held mobile phones while operating a vehicle. At the federal level, the National Highway Traffic Safety Agency has initiated a research program to formulate design and safety guidance for developers of in-vehicle information systems.

The purpose of this report is to review research in the areas of attention and situational awareness, as it pertains to safe and effective job performance in first responder operations. The goal is to outline a research path that will lead to general design principles to guide development of individual technologies and operational concepts. Properly designed wearable and mobile information augmentation devices can enhance situational awareness, while accommodating the capacity limitations inherent in humans.

NGFR concepts were foreshadowed by military projects such as the Land Warrior system, developed initially as the Soldier Integrated Protective Ensemble, and various subsequent evolutions. These systems entail the integration of protective combat gear and information for situational awareness, including helmet-mounted displays of maps and locations of blue and red forces (Zieniewicz, et al., 2002; National Research Council, 1997).

The most recent Department of Homeland Security responder technology roadmapping exercise, Project Responder 4 (DHS, 2014) addresses situational awareness technologies as a key enabling element. According to this report:

> **Situational awareness** is defined as the capability to obtain and distill specific knowledge concerning threats, hazards and conditions in a timely matter to support incident management decisions across all phases of a catastrophic incident response, including
> - The ability to know the location of responders and their proximity to risks and hazards in real time
> - The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time
> - The ability to rapidly identify hazardous agents and contaminants
> - The ability to incorporate information from multiple and nontraditional sources (for example, crowdsourcing and social media) into incident command operations

This definition of situational awareness focuses on data availability in real time and suggests increased speed and volume of information flow for responders. These functional capabilities are envisioned as integrated within the personal protective equipment of first responders, such as HMDs with on-scene overlays, body-worn biohazard and physiological sensors, and various location-based tracking mechanisms. Situational awareness, however, is more than increased data availability and depends on the interplay of the cognitive processes of attention, memory and decisions for action, which are discussed further in this report.

The general paradox of wearable and mobile information technologies is the increased *accessibility* of multiple streams of information with the concomitant reduction of *attention* to those sources of information (Norman, 2013). Even the simple presence of a cell phone (without using it or in silent mode) can change the nature of interaction between people, affecting closeness, connection, and conversation quality (Przybylski & Weinstein, 2012; Misra, Cheng, Genevie & Yuan, 2014).

On a more fundamental level, wearable and mobile technologies can change the conscious experience of humans, affecting what we attend to, how fast we react, and meanings ascribed to data. The research data reviewed in this report suggest that wearable and mobile technologies can re-orient people's thinking to sources of information outside the immediate context, often at the expense of task performance quality and effectiveness. For example, simply receiving a notification that a call or message has arrived on a cell phone can significantly disrupt attention and performance (Stothart, Mitchum & Yehnert, 2015). This can result in "imagined" input, as experienced by a large number of people reporting "phantom vibration syndrome" from a device that is not really vibrating (Lin, et al., 2013). Such real or imagined input can prompt task-irrelevant thoughts that persist much longer than the notification. It is thus important to address how best to design and deploy these technologies for first responder jobs that are heavily dependent on attention and situational awareness for immediate context in rapidly evolving situations involving a high degree of stress.

This report reviews and synthesizes research in the following areas:

- Studies of first responder cognition and task performance
- Theories of human information processing and attention
- Studies of the effects of wearable and mobile technologies on attention and human performance in driving, military systems, and first responder applications

The findings are integrated to make recommendations for NGFR applied research and design to support the practical development of wearable and mobile technologies that can safely function within the attention envelopes of first responder operations.

2.0 Emergency Response Operational Context

The work context of emergency first responders has common operational elements, including:

- Time Pressure
- Uncertain, dynamic environments
- Ill-structured problems
- Shifting, ill-defined or competing goals
- High stakes
- Multiple players
- Organizational goals
- Information inputs from many sources

These characteristics of emergency response occur across fire, police, and emergency medical situations (Zsambok & Klein, 1997). The last of these characteristics—*information inputs from many sources*—is the primary focus of this report, as it is most pertinent to the issue of attention and situational awareness, and the potential impacts of new wearable technologies.

For each emergency response type, multiple and sometimes rapidly changing information inputs come from diverse sources, including initial size-up of a fire-ground situation, threat assessment of potential suspects for police, and patient presenting symptoms and medical history for Emergency Medical Services (EMS). Each of these broad categories has numerous visual and auditory information elements, such as the extent of fire and size and access elements of a building, the physical characteristics and manner of suspects, and vital signs and verbal reports from patients. Additionally, each emergency responder is generally monitoring radio communication for information that might be relevant to the situation at hand.

Mobilizing attention to achieve situational awareness in these situations is a continuous process of monitoring/sampling the environment, deciding on courses of action (including gathering more information), and implementing actions. This cycle is represented graphically in Figure 2.

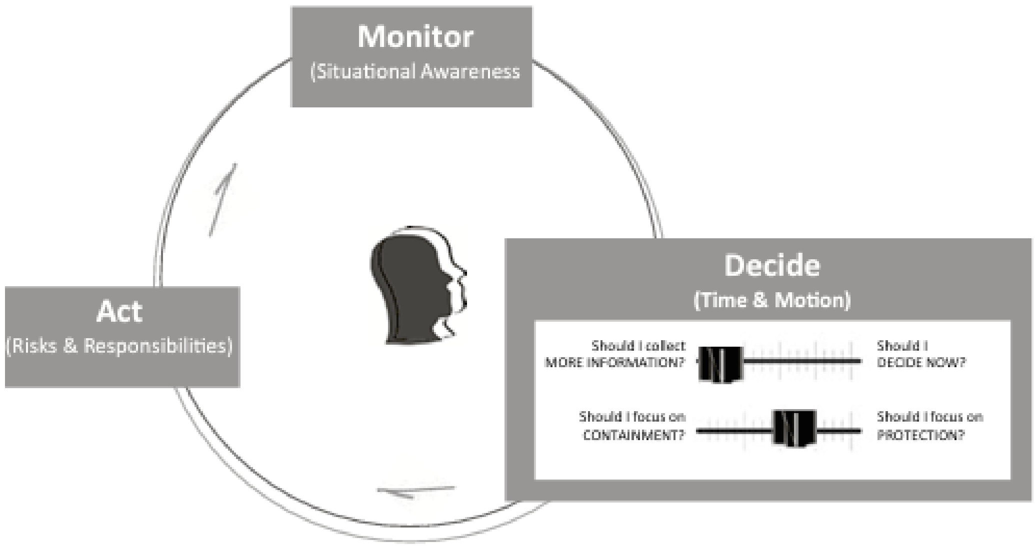

Figure 2. Interaction of situational awareness, monitoring, decsion, and action.
(Source: Frye & Wearing, 2014)

The multiple visual and audible information streams can challenge the ability of responders to comprehend what is relevant to the immediate situation. Each emergency response type has developed practical methods for managing information flow during deployments. For example, communication protocols are used to address radio traffic "chatter," such as a fire-ground team selecting a sub-channel frequency limited to the deployed team.

With developments in wearable and mobile communications technologies, more potential information sources are available to the responder. The demands on the attentional process are likely to increase unless design and deployment address the fundamental role of attention and the potential for information overload.

3.0 Conceptual and Theoretical Background

Ideas about human cognitive functional limits have been part of psychological theories since the 19^{th} century. For example, specific limits on immediate memory were demonstrated in early experiments by Ebbinghaus (discussed in Woodworth, 1938). Empirical studies also illustrated limits in the ability to attend to multiple things at once, to respond quickly to sudden occurrences, and various "higher level" functions such as problem solving.

This knowledge base has been progressively refined and applied in military and commercial settings, initially for personnel selection on the basis of individual differences in skills or aptitudes, and later for equipment and software design. Applications to communications involved designs for telephone dials, keypads, and the configuration of number system exchanges, with the goal of reducing errors and dialing time for operator-assisted connection (Karlin, 2003).

Studies of communications between air traffic controllers and pilots identified difficulties in listening and distinguishing multiple audio inputs. Subsequent research studies yielded results that were interpreted within the developing field of cybernetics and information processing, and led to formulation of the limited capacity human information processor concept (Figure 3). The basic premise of this concept is that humans can process information at a finite rate, and any tasks or equipment that exceed that rate will lead to errors (Kantowitz, 1983). Human information processing models represent various cognitive subsystems that transform, transmit, and store information. These subsystems are sensory, perceptual, and memory processes, and they are modulated by means of attention (Wickens, 1982).

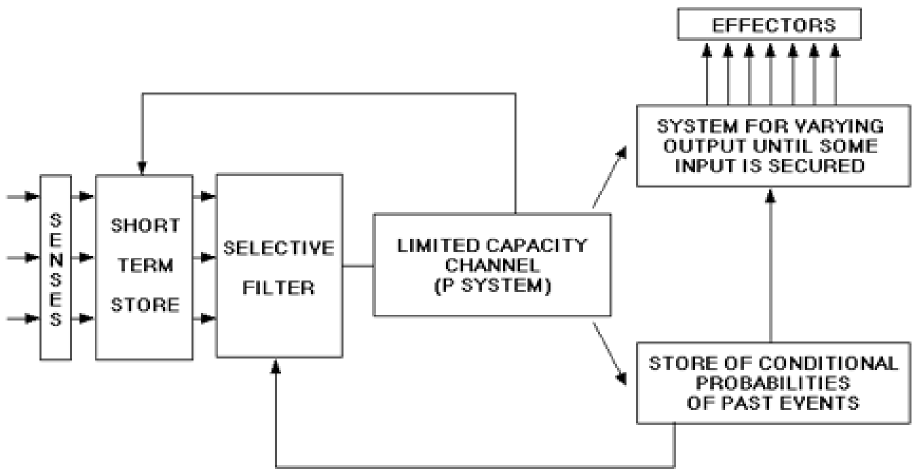

Figure 3. Limited Capacity Human Information Processing Model.
(Source: Broadbent, 1958)

The basis for a human-centered design approach to promote safety and error reduction is the limited capacity human information processor model, and the associated methods and data concerning human capabilities and limitations. While human-centered design has found widespread application in military and certain transportation contexts (such as aviation), much less attention has been given to this approach in designing equipment for emergency responders.

The original formulation of the limited capacity model was based on observations of human performance difficulties with increasing levels of technology. The core elements—selective attention to information inputs, interference among similar inputs, and the limited duration of non-attended information—are especially relevant to situational awareness technology design for first responders, in order to ensure that increased data availability is translated to task-relevant information (Figure 4).

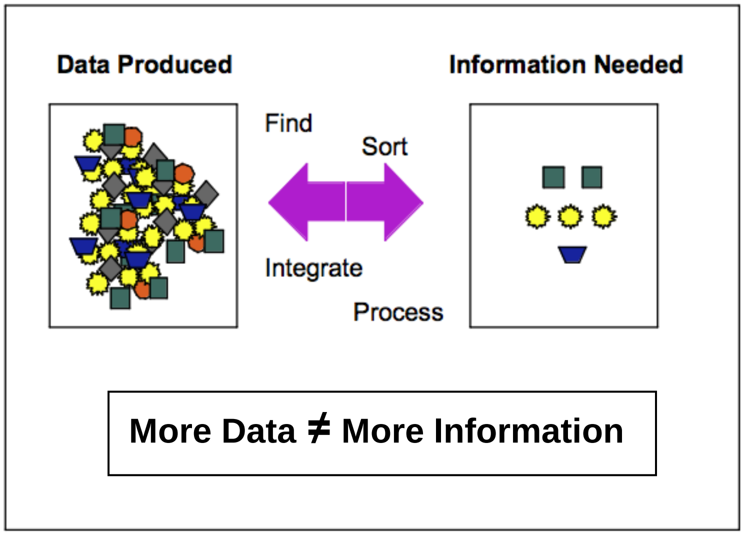

Figure 4. Process of Bridging Information Gap.
(Source: Endsley, 2000)

4.0 First Responder Operations – General Characteristics of Cognitive Processes and Decisions Under Time Pressure

The nature of emergency first response involves extreme time pressure, often confusing situations with emerging characteristics, and high stakes consequences associated with selected courses of action. These types of events are difficult to study with the traditional methods of experimental psychology. However, adapting the applied method known as the *critical incident technique* (Flanagan, 1954) allowed Klein et al. (1986) to conduct a study of decision making on the fire ground by first responders. This work led to the theory of "recognition primed decision making" or "naturalistic decision making" (Klein, 2008).

This theory holds that in time-pressured situations, where concurrent evaluation of alternatives is not possible, experts will choose a course of action that they remember having chosen in a similar situation before. Thus, their decision making ability is based on whether or not they can recognize a given situation as "typical," meaning that experience plays an important role in the process (Klein et al., 1986). While this theory of decision making was originally developed in response to research with fire ground commanders, studies of expertise in other domains have supported its basic elements (Johnson & Raab, 2003); Klein, Wolf, Militello & Zsambok, 1995). Recognition of specific types of situations is based on the event "size-up," which can involve prior knowledge of building types and plans, as well as specific contextual elements from the event of concern (Terpak, 2002; IFSTA, 2013).

Zimmerman (2008) asked experienced and novice police officers to narrate their thoughts as they watched a video of a traffic stop and found that expert officers tended to make decisions based on past experience, without stopping to weigh multiple choices. Similarly, Uttaro (2002) found that police decision making in a series of interview-based case studies and observation aligned with the principles of naturalistic decision making.

As for paramedic decision making, emergency physicians (who play a similar role to paramedics) have been shown to also rely on naturalistic decision making (Croskerry, 2002), and a study of EMS decision making found that as paramedics become more experienced, they depend less on step-by-step processes and more on their ability to automatically recognize and respond to clinical issues (Wyatt, 2012).

Given the manner in which first responders must make quick decisions in uncertain environments, one of the elements of this style of decision making is the ability to recognize a given situation as "typical," so as to allow for successful matching of the situation to an appropriate course of action. Thus, effective decision making largely stems from an expert's comprehension and understanding of the situation at hand (Endsley, 2000; Klein et al., 1986; Randel, Pugh & Reed, 1996; Stanners & French, 2005). This knowledge has been termed "situational awareness" and consists of one's ability to 1) perceive environmental factors that relate to the task or mission at hand, 2) understand the meaning of those factors, and 3) predict how those factors will influence or determine the situation's trajectory. While situational awareness depends on a variety of factors, one of its principal foundations is that the operator is able to pay adequate attention to the environment. According to Endsley (2000), one of the most frequent contributors to situational awareness failures is operators neglecting to attend to available information, which is often due to distraction imposed by other tasks (Figure 5).

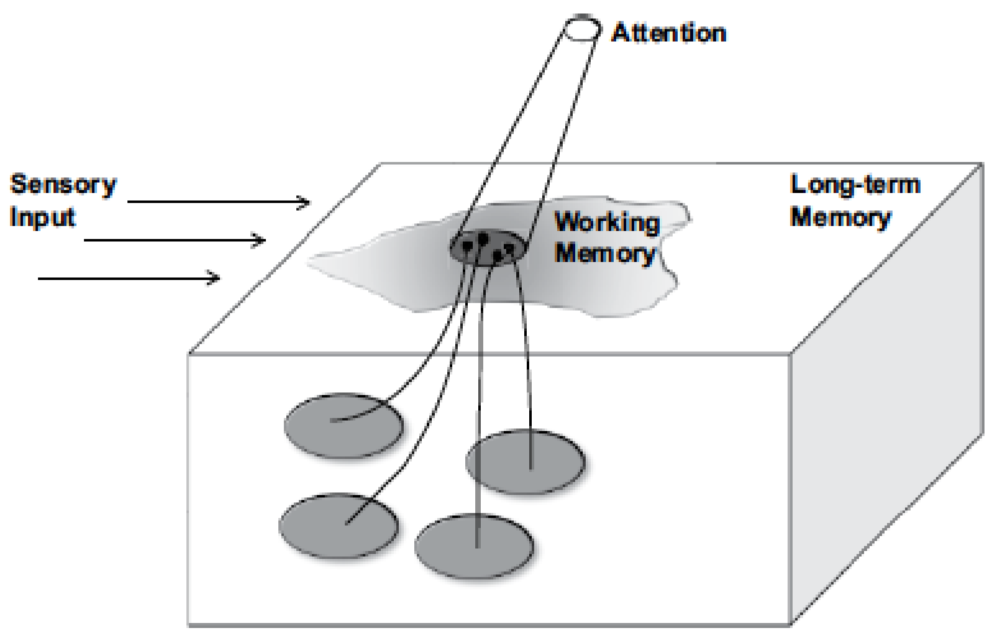

Figure 5. Interaction of attention to sensory input, activation of memory and situational awareness. (Source: Endsley, 2000)

4.1 First Responder Operations – Characteristics of Fire, Police and EMS Cognitive Processes and Decisions

Research has shown that while first responders, regardless of their role or function, tend to base their decisions on their ability to recognize a situation as typical, and they respond based on experience, differences exist among the various first responder functions as to how such decision making occurs. Understanding how these roles and responsibilities vary is important to consider in the design of first-responder-oriented technology, as user requirements may vary by domain.

Firefighters follow a set command structure that requires a high degree of coordination and communication in emergency situations (Fern, 2008). To conduct operations, firefighters require a great deal of information about other team member's activities, the environment, and their own status (air levels, location, etc.)(Fern, Trent & Voshell, 2008). Commanders obtain much of the information they need through scanning the environment and through communication with their subordinates (Lipshitz, Omodei, McLennan & Wearing, 2007). While commanders' decisions are often based on experience, operations in general are largely based on established standard operating procedures (Lipshitz et al., 2007). When communication breaks down, leading to emergency situations, individual firefighters resort to making decisions on their own, often based on immediate environmental cues and nearby team members, sometimes neglecting the needs and operations of distant or unseen team members (Fern, 2008).

Paramedics employ a variety of strategies in order to make effective clinical decisions. One such strategy is pattern recognition, in which certain combinations of symptoms are automatically recognized and matched with the paramedic's past experience in order to generate a course of action (Hagiwara, 2014). Another commonly used strategy is the Rule Out Worst-case Scenario strategy, in which the paramedic examines the patient to determine the likelihood that they are suffering from the most dangerous possible condition (Hagiwara, 2014; Jensen, 2011). Still another strategy is algorithmic thinking, which is based on established treatment protocols and involves mentally walking through a step-by-step process to assess and treat a patient (Hagiwara, 2014; Jensen, 2011). Experienced paramedics tend to gravitate to more intuitive, pattern-recognition methods of decision making; however, they will often revert to algorithmic processes in difficult or unfamiliar situations (Wyatt, 2012). Even when paramedics deviate from established protocols as they become more experienced, studies examining the effectiveness of protocol-based computer aids have found that paramedics' task order is generally amenable to modification and can be re-aligned with such procedures (Hagiwara, 2014; Sasse & Johnson, 1999). Expert paramedics focus on obtaining as much information as possible from the patient, often switching attention rapidly between multiple patients (if applicable) in order to perform as many tests as possible (Smith et al., 2013; Wyatt, 2012). Expert paramedics are also hesitant to make overly specific diagnoses early on, and maintain a range of diagnostic hypotheses to inform treatment (Smith et al., 2013; Wyatt, 2012).

Law enforcement officers respond to a variety of events and emergencies and are encouraged to rely on intuition[1] when making decisions regarding incident response (Elliot, 2014). Improvisation is an important ability in some situations (Uttaro, 2002), and expert officers are typically skilled at analogical reasoning, which involves ascertaining the relationships among the cues in the environment and comparing them to a more familiar situation in order to determine an appropriate response (Elliot, 2014). Law enforcement officers pay close attention to suspects they are interacting with in order to predict whether or not they will be an immediate threat (Helsen & Starkes, 1999; Zimmerman, 2008), and they also scan their physical environment for details that will help them create a cognitive map of a situation (Uttaro, 2002). Law enforcement officers are unique in their ability to sometimes prepare for an operation beforehand, which is an essential step in the process (Uttaro, 2002). Knowing the details of an operation

[1] Intuition, as used here, is meant to convey situation recognition based on experience. It is not a "sixth sense," but instead recognition of types of situations based on cues provided in the environment (Simon, 1992).

beforehand allows officer to mentally simulate “worst case scenarios” before beginning the operation in order to facilitate appropriate responses to adverse events (Uttaro, 2002).

4.2 First Responder Situational Awareness and Decision Making: Summary and Knowledge Gaps

The general characteristics of the various first response functions can be summarized as follows:

- Firefighters depend heavily on communication with one another in order to maintain adequate situational awareness. For commanders, decisions are made based on both established protocols and memories of past experiences. When communication breaks down, this can force individual firefighters to make decisions based only on their immediate surroundings and teammates, oftentimes being unable to take into account other factors.
- Paramedics rely on protocols and step-by-step processes to treat patients. Experience causes many of these processes to become automatic and allows paramedics to immediately recognize and treat a problem, but adherence to protocols is still valued and resorted to in unfamiliar situations. They gain situational awareness by performing as many medical tests as possible and remaining open-minded about possible diagnoses.
- Law enforcement officers rely heavily on behavioral cues to predict the behavior of those with whom they interact. Situational awareness depends mostly on observation of these cues as well as features of the environment that can help form a mental map. Individual decision making is common, and often based on experience. In pre-planned operations, preparation beforehand is a critical step in successful police work.

Table 1 compares the three first responder functions on the in terms of how situational awareness is acquired and the basis for recognizing types of situations within the naturalistic decision making framework. It is readily apparent that *direct observation* is the key method of data acquisition, and that recognizing and classifying situations is based on experience and protocols.

Table 1. Comparison of First Responder Approaches to Situational Awareness.

Function	**Situational Awareness acquired through…**	**Basis for Situation Assessment and Classification**
Firefighters	Direct observation and communication with teammates	Mostly past experience, some protocols
EMS	Observation of patient, Active medical testing	Protocols and past experience
Police	Behavioral observation	Mostly past experience

These conclusions are based primarily on research using retrospective reports and interviews with responders, and are thus biased toward what might be called “macro-cognition,” (i.e., the more global aspects of situations such as type of fire, medical emergency or enforcement activity) rather than the "microstructure" of how the senses were deployed and attention shifted in rapidly evolving emergencies. These latter cognitive processes (e.g., where the eyes are focused, how often they are shifted, verbal communications over multiple channels, second and third looks for subtle behavioral cues in suspects) tend to occur at the level of tens of milliseconds and in high volume. As a consequence, the primary cognitive functions that underlie situational awareness are much more difficult to recall and articulate following the event. However, effective naturalistic decision making in emergencies is heavily dependent on the ability to fluidly deploy the sense organs and attention.

General concern exists among first line emergency responders that wearable and mobile technologies will result in "information overload," particularly if they are being directed by command personnel viewing various "situational awareness technology feeds." Wearable technology developed for first responders can thus impact their decision making ability (either for better or worse), depending on how such technology interacts with responders' attentional focus. Such technology should be designed in a way that promotes effective decision making through increased awareness and comprehension of the challenging environment that emergency responders must navigate. Displays or communication equipment that prove distracting to the responder may not only make their tasks more difficult, but may compromise both their safety and the safety of those they are responsible for, by inhibiting their alertness and awareness of the changing dynamics around them.

Thus, a key knowledge gap in first responder situational awareness concerns the specific mechanisms of attention to the emergency environment that allows situational awareness to be developed and updated, and courses of action implemented. We can address this gap by drawing on the considerable basic and applied research field devoted to the mechanisms and processes of human attention, and applied studies of performance in cognitively demanding activities such as driving and aircraft piloting.

5.0 Attention: A Foundation for Situational Awareness

It has become commonplace in numerous domains to discuss situational awareness as the enabler of effective human performance in complex circumstances. Psychology tends to treat situational awareness either as a process (a series of interacting cognitive operations) or a product (an end state representing current circumstances). Technology developers tend to equate situational awareness with data and the means of delivering it; hence, the emphasis on wearables. Front-line personnel are more practical in their representation, focusing on data as well as the linkage of immediate perception to memory; hence, naturalistic decision making. The most practical definition of situational awareness is provided by the Federal Aviation Administration (Byrne, 2015) simply as "knowing what is going on around you."

The extensive theoretical treatment of situational awareness in the past 20 years has largely by-passed the fundamental role of attention in favor of elucidating the various levels and interaction of sub-states of awareness. Endsley (1995) illustrates attention as an overarching moderator of situational awareness, and there is general agreement in the literature that attention is a critical factor. However, there remains relatively little connection between models of attentional processes, theories of situational awareness, how attention is directed in specific circumstances, and the implications for technology design for particular applications. In this section we review some of the fundamental neural structures and concepts of attention, with a view toward better understanding its role in first responder situational awareness and the potential impact of wearable and mobile technology.

5.1 Neural Subsystems of Attention – The Hard-Wiring

Considerable progress has been made in delineating the neural structures underlying attention. During the same period that human studies of selective listening were characterizing the limited capacity human information processing model (Broadbent, 1958), research with animals was beginning to suggest the existence of specific neural mechanisms underlying attention (Hernandez-Peon, 1956). There is general agreement currently that distinct neural structures and systems serve the processes of being *alerted* by something in the environment, *orienting* toward the source, and maintaining *executive control* via focused attention toward important sources (Peterson & Posner, 2012). Neuroimaging and electrophysiological studies have identified cortical and subcortical structures that are distinctly activated by different aspects of attention, although there is some degree of overlap (Figure 6). Attentional mechanisms, notably alerting and orienting, have involuntary characteristics, which may be modulated to some extent by executive control.

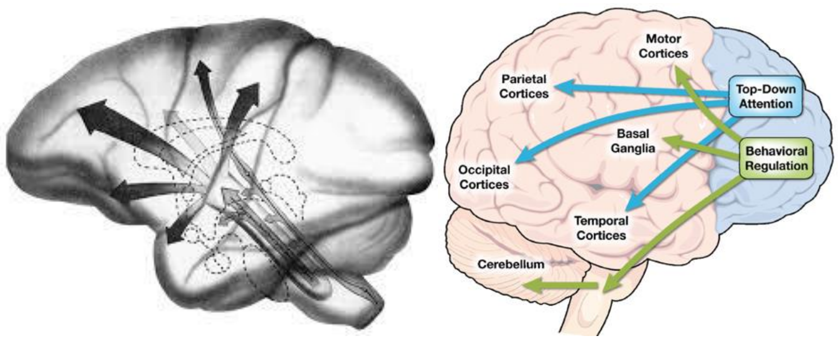

Figure 6. Brainstem reticular activating system and cortical systems of attention.
(Source: left, Magoun, 1963; right, Arnsten, et al., 2009)

Alerting and orienting responses are primarily based on sensory reception and activation from the reticular activating system, and direct the sense organs and attention to the source. A simple example is a warning signal in a vehicle, usually a sound if the warning is critical. This serves to alert the driver, who then investigates further by glancing at the instrument panel – a process mediated by the cortical executive control system.

Eye movements are an excellent example of the operation of all three elements of the neural attention system. The visual system is attuned to novelty and contrast from earliest infancy. This serves an alerting and orienting function of fundamental adaptive significance. These "stimulus-driven" or "bottom-up" dispositions are maintained throughout life and influence both spontaneous viewing of scenes as well as environmentally based movement of eyes and attention. Kahneman (1973) reviews work on spontaneous and directed "looking," which is still quite relevant today as it describes what are essentially hard-wired aspects of the neural attentional systems. The most relevant aspect of this research for considering the neural basis of attention are:

- Gaze is attracted by many contours, novelty, complexity or significance.
- Intentions can override these fundamental tendencies.
- Sudden change will evoke an orienting reaction and change of visual fixation (this has analogues in the other senses as well).
- Eye movements tend to be inhibited during attentive listening.

More recent electrophysiological and neuroimaging studies in humans support these generalizations from studies of eye movements (Peterson & Posner, 2012; Kowler, 2011). Further, studies of eye movements in naturalistic behaviors (such as preparing a meal and driving) illustrate that gaze is directed to those areas that are most task relevant (Hayhoe, 2010); the tendency to look at contours and novelty reflects information that is or may be task relevant. Other applied research studies show that low current transcranial direct magnetic stimulation over the frontal cortex in human observers can enhance detection of threat targets in realistic images (Parasuraman & Galster, 2012), suggesting an eventual ability to augment the attentional control system based on current tasks.

5.2 Attentional Processes – Applications of the Hard-Wiring

The study of neural structures of attention focuses on identifying and describing brain systems, while psychological studies aim to characterize the cognitive and job/task factors that influence human performance. The principal means for doing this is to study human responses in tasks that isolate the fundamental elements of complex work situations. Among the earliest questions asked by psychologists was "How many things can we attend to at once?"

Studies of multi-channel listening were originally undertaken to better characterize the performance of early air traffic controllers and to guide the design of audio speaker systems for communications. Filter Theory (Broadbent, 1958) was the outcome of studies of selective listening using a procedure illustrated in Figure 7, in which a listener repeats what is heard in one ear and ignores (or attempts to) the sounds in the other ear. This situation is analogous to a first responder listening to a team member describe a situation, while continuous radio communication is played over their handset. The radio communication is necessary – it cannot be turned off – but the primary concern is the face-to-face communication with their team member.

Figure 7. Selective listening task: Message contents can lead to unconscious shifts of attention. (Source: Bopp, 2012)

Two themes were articulated by Broadbent's 1958 formulation: *limited capacity* for processing information and a *selective filter* that allows some inputs into awareness, but not others. These two themes are at the core of every psychological theory of attention. In this section we review some of the main findings and themes that are useful for guiding displays and information streams for first responders.

The first theme – limited capacity – is well-described by the following quotation:

> All these experiments, then, agree in general that an increase in the amount of information presented will not produce a corresponding increase in the amount of information assimilated. To

> some extent, two messages may be dealt with simultaneously if they convey little information. But there is a limit to the amount of information which a listener can absorb in a certain time, that is, he has a limited capacity. (Broadbent, 1958, p. 17)

The second theme – a selective filter – is characterized as a frequency band-pass receiver attuned to some radio frequencies while reducing or eliminating others. The receiver "knows" something about the physical characteristics of the interference – the frequency but not the content conveyed (the message in the radio signal). In the same way, listeners will possibly know that the voice of a speaker in the non-attended message is female but not the words spoken. However, if the listener's name is mentioned, or the content of the message is related to the attended ear, the listener is likely to switch to the un-attended ear. Many years of successive refinement from various types of attention experiments have succeeded in elaborating cognitive theories of attention, although the specific limits and nature of the selective filtering process remains elusive.

Since the publication of Kahneman's book *Attention and Effort* (1973), the characterization of attention has changed from a *structural* model as exemplified by Filter Theory, to a *resource* model, in which variable cognitive resources are deployed according to task demands. Resource models were developed to account for results from experiments in which people are required to perform two tasks at the same time, such as detecting a visual target while simultaneously doing mental arithmetic. During periods of very high demand on the mental computation task, target letters are not detected as well. Interference between simultaneous tasks – essentially doing two things at once – occurs, based on such factors as the amount of effort required (e.g., a well-practiced activity vs. an unfamiliar activity), sensory modes used (visual, auditory, touch), and the relative importance of those tasks (Wickens & McCarley, 2008; Kahneman, 2011).

A well-known example of attentional interference is the experiment in which observers view a short film and are required to count the number of times a basketball is passed between participants. About halfway through the film, a person in a gorilla suit walks through the scene (Figure 8). Less than half of the viewers noticed the gorilla, even under fairly easy task loading (Simons & Chabris, 1999). This kind of interference is referred to as *inattentional* or *change blindness* and describes the general case of "looking but not seeing." Similar effects occur with auditory primary tasks and by redirecting attention, but not the eyes. This latter type of effect – re-orienting attention – gives rise to the "spotlight" metaphor and is also referred to in the literature as attentional narrowing or cognitive tunneling. Neurophysiological and psychological demonstrations of this type of result suggest a neural "gate" and a volitional control over the "orientation" of attention that is not dependent on sensory focus (Posner, 1980). Regardless of terminology, the effects are the same: a restriction in the "attentional field" limits what enters awareness.

Figure 8. Inattentional blindness: Observers fail to notice gorrilla if they are payng attention to other elements of scene such as shirt color or movements.
(Source: Simons & Chabris, 1999)

The practical implications of demands upon attention tend to be seen in complex operational settings, such as piloting an aircraft, controlling a power plant, air traffic control, and operating a motor vehicle under. In each of these cases, there have been documented failures of attention (e.g., failures to notice changes in flight mode, safety-related changes in altitude, etc.) (Wickens & McCarley, 2008). People also incorrectly assume that changes will be noticed; they overestimate the extent to which their knowledge of the ongoing situation is current (Levin, et al., 2000). This latter finding underlies drivers' sense that it is not a problem to talk on the phone and drive at the same time, an issue discussed further in this report.

5.3 Distraction

Distraction is often considered the opposite of attention – some external or internal information that reduces the ability to focus on elements of the environment that are important for job performance. Examples of external distractions include ringing mobile phones, loud conversations, and sudden changes in the scene being observed. Internal distractions can involve thinking about something that is not related to the task at hand, such as family or money issues, or can involve getting very highly focused on some aspect of a task (such as finding a parking place) to the exclusion of other elements of driving (such as the presence of pedestrians in front of the vehicle). It has been proposed that "inattention" is a result of internal distractions and that external distractions prevent the effective maintenance of attention (Regan, et al., 2011). In most situations, these distinctions are not entirely clear-cut. For example, simply carrying a mobile phone that is powered on while driving can constitute either an internal distraction ("I wonder when he will call") and an external distraction, such as a text message arriving during a demanding stretch of driving. From a practical standpoint, distraction can be considered as a demand on attention (voluntary or reflexive [e.g., top-down vs. bottom-up]) that reduces focus on the task of primary importance for effective job performance and safety.

Attention theory and neurophysiology have clear implications for first responders. Sizing up situations for fire, law enforcement or EMS depends on rapid sampling of critical features of emergency situations encountered. Thus, the basic elements of the neural hard-wiring and attentional processes come into play at the outset of an emergency. Examples include distinguishing competing acoustic messages on the radio, focusing on the relevant channels while filtering out the rest, being alerted when critical information comes across an "un-attended" message channel, and visual scanning for critical features (e.g., type of street access for a building, traffic, behavior of bystanders, etc.). This visual scanning is done in the context of continuous monitoring of radio communications, and the effectiveness of both listening and looking interact. Eye movements, for example, tend to be reduced when engaged in intensive listening (this also has implications for driving, as discussed below).

While standard operating protocols and practices have evolved to facilitate effective attention and situation awareness in these situations, distractions do occur. Examples include excessive radio "chatter," unexpected demands from other agencies in complex emergencies, failure of equipment and the consequent focus on resolving that rather than working around it; all of these situations occur in the routine flow of operations. Adding new technology in the form of wearable devices can be considered equivalent to introducing new "information channels" that represent demands on attention or distraction. The next section discusses research that illustrates the impact of distraction upon driving performance, which has distinct impacts in the emergency response community.

6.0 Distracted Driving: Attention to Driving or Attention to Mobile Phone or In-vehicle Display or Passenger?

Driving is a task that obviously requires attention. Awareness of the driving environment depends on cognitive processes including Scanning the visual field, Predicting what might happen, Identifying situations and objects, Deciding what to do next and Executing various driving Responses, or SPIDER (Strayer, 2015). This attention-driven cycle is the basis for situational awareness in driving and virtually all other complex activities that people perform. The SPIDER model is very similar to the Monitor-Decide-Act cycle of situational awareness used to describe first responder activity (see Figure 2). Thus, driving is a convenient model for the psychological processes that underlie first responder job performance and a useful way to study the potential impacts of various situational awareness technologies upon attention and performance.

Concern about the safety impacts of in-vehicle technology occurred initially in the 1930s as radios became standard features of cars (Strayer, 2015). In that same period, the first two-way radios were installed in police cars. Crash reports consistently show that inattention due to in-vehicle sources such as radio, climate controls, or other instrument cluster interactions are associated with collisions (Wang, Knipling & Goodman, 1996). Since the invention of the cellular phone in the 1970s, most states have passed laws prohibiting texting while driving, and 14 states prohibit use of a hand-held phone while driving (Governors Highway Safety Association, 2015). A survey of 6,000 adult drivers (Tison, Chaudhary & Cosgove, 2011) found that well over half the sample reports answering calls while driving, and that half of these respondents believed it made no difference in their driving performance. However, as *passengers*, 40% of the respondents indicated they would feel unsafe if the driver were having a cell phone conversation. The disparity between self-perception of safe behavior versus that of others points to potential difficulty in changing behavior: "It is OK if I do it, but not if others do."

The focus of regulation on hand-held devices does not address the attentional costs of conversing on headsets or via phone service through the vehicle sound system, nor the interactions with an increasing number of integrated console displays for navigation and entertainment. The availability of these technologies, which do not necessarily add anything to the safety or efficiency of the driving tasks, often compels their use, and the increasing array of features that entail voice interaction also requires attention. In this section we examine some of the major findings from research on technology-based driver distraction, which can serve as an indicator of similar potential problems with first responder situational awareness technologies.

6.1 Distraction in routine driving

It has been known for a long while that impaired driving performance is not simply a matter of "eyes-off-road" associated with dialing or answering. Brown, Tickner and Simmonds (1969) conducted a test track driving study in which audio information was presented via speaker and responses made via headset – no physical interaction with a device was required. The results indicated that perceptual judgments of gaps through which a vehicle could pass were impaired in all but the largest space. This was interpreted to mean that the attentional demands of the conversation task reduced the capacity for making safe distance judgments while driving. Many subsequent studies have confirmed and elaborated this basic finding and shown detrimental effects of mobile phone conversation upon brake reaction time, hazard detection, responding to highway signs, and vehicle steering (e.g., McKnight & McKnight, 1993; Reed & Green, 1999; Horrey & Wickens, 2006).

A consistent finding in driver distraction research is that of the graded impact of various in-vehicle distractions. McKnight and Mcknight (1993) demonstrated a reliable difference in failing to respond to traffic situations between conversations that were casual versus more demanding. More recently, work by Strayer (2015) shows that speech-to-text interaction with in-vehicle systems is among the most attention-demanding tasks and is associated with higher levels of distraction and performance impact (Figure 9).

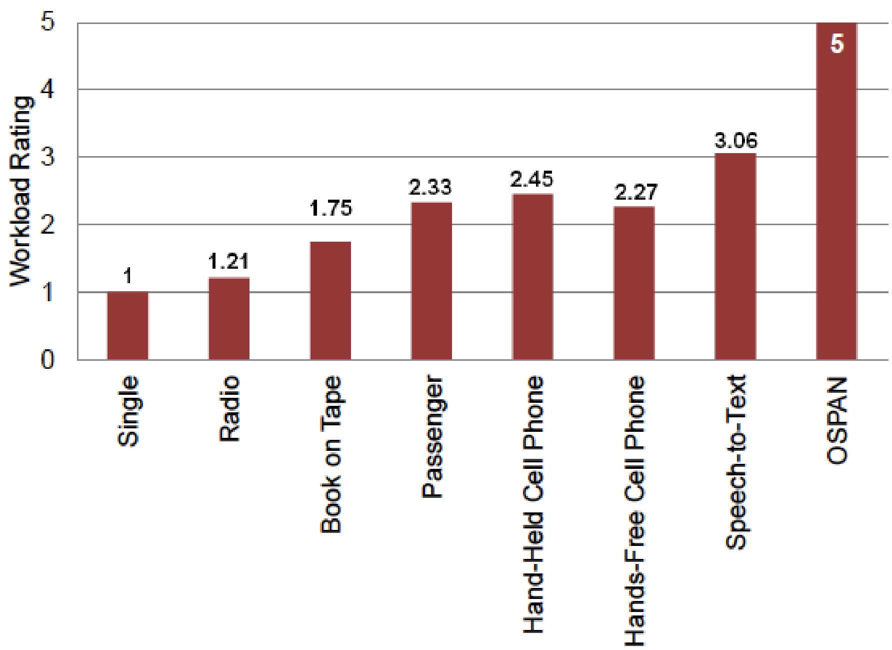

Figure 9. Graded levels of cognitive distraction based on aggregate measures of driving performance. OSPAN task entails a complex arithmetic/verbal memory load and judgment. (Source: Strayer, et al., 2013)

While talking to a person remotely is distracting at a moderate level, it has been shown that passengers will adjust their conversation based on their view of the driving scene, thus becoming an adjunct workload manager (Charlton, 2009). Comparisons of driving performance with cell phone distractions to conditions in which the driver is legally intoxicated shows that both types of impairments degrade driving compared to baseline (Strayer, Drews & Crouch, 2006).

The pattern of results obtained from the various studies of driver distraction suggests that fundamental attentional mechanisms are being affected, somewhat independent of manual control. Additionally, basic research on attention indicates that the cell phone communication (or in-vehicle electronic interaction generally) re-orients attention to more of an internal focus. The "functional field of view" appears to narrow as a result of competing attentional demands. Support for this idea is provided by Atchley and Dressel (2004), who showed that a conversational secondary task significantly increased the time required to detect targets presented in the visual periphery; no driving was involved.

Studies of eye movements, which are directed by "top down" attention, tend to show a very restricted pattern for drivers engaged in cell phone conversations (Figure 10). The centrally mediated attentional demands of remote conversation via hands-free phone reduces the effectiveness of a core behavior in driving: visually scanning the environment. This effect is even more pronounced when drivers interact with speech-to-text systems such as Apple Siri, which has a relatively brittle interface; Siri requires exact phrasing, and subtle changes result in failure and the need to start over. This type of interaction, which is being heavily promoted for hands-free wearable devices of all kinds, is much more mentally demanding than direct interactions with passengers or two-way conversations via cell phone (Strayer, 2015). As suggested by Strayer, et al. (2013), "Hands-free does not mean risk-free."

Figure 10. Distribution of eye movements for drivers not using cell phone (left) and when using a hands-free phone (right).
(Source: National Safety Council, 2012)

6.2 Distraction in Emergency Response Driving

Technology-based distraction occurs for first responders as well as average citizen drivers. James (2015) reports a study in which experienced police officers drove high-fidelity simulation courses with and without a task designed to mimic interaction with a mobile data computer. The distraction condition resulted in greater lane deviation and longer braking reaction times—effects identical to average citizens who are less likely to be interacting frequently with communications equipment. The distraction effect is seen in emergency vehicle accident statistics, in which inattention is cited as a major factor (46%), and several studies citing technology in the vehicle as a contributor (Yager, et al., 2015). Examples of emergency vehicle technology in use today is shown in Figure 11.

Figure 11. Types of mobile computer terminals installed in emergency vehicles.
(Left) Fire engine, (right) police cruiser. (Source: Yager, et al., 2015)

According to the Yager, et al. (2015) report, there is concern among various local jurisdictions that distraction is a growing problem for emergency service vehicle drivers. While statistical reporting is sparse, this research team reported illustrative anecdotal evidence, gathered from local police reports. Several of these examples follow:

- In August 2014, an ambulance driver in Columbus, OH veered off the road and crashed into the guardrail and rolled over multiple times. The patient onboard died due to injuries experienced when he was ejected from the vehicle. The driver admitted to being distracted and looking at the GPS device, trying to determine the estimated time of arrival to the hospital.
- In May of 2010, a distracted officer in Austin, TX ran a stop sign and crashed into a 74-year-old man on a motorcycle who suffered multiple injuries. The police report showed that the officer was adding notes into the mobile computer terminal when the crash occurred.
- In 2011 an ambulance was responding to a non-emergency call in Huntington Beach, CA when it hit multiple vehicles stopped at an intersection. The police report states: "(The driver) was reading about the medical call he was headed to on the ambulance mobile data computer and as he was reading the call, he heard his partner in the passenger seat yell 'whoa.'" Without the passenger's verbal warning this crash may have been even more severe.

These examples make it clear that emergency responders are subject to the same driving performance impairments that average citizens experience. It might be argued that they are even *more* susceptible to these effects during high stress activities such as high-speed driving and emergency patient transport. Finally, drivers are aware of distraction effects on performance, but there is no relationship between their assessment of distraction on a moment-by-moment basis, and impairment in performance (Horrey, Lesch & Garabet, 2008). This suggests drivers (including first responders) will not be able to effectively compensate for technology-based distraction.

7.0 Military and Aviation Situational Awareness

NGFR concepts and requirements for connectivity and situational awareness show many similarities to programs initiated by the military and NASA to bring digital data and displays to aviators and dismounted soldiers. Most of these systems focus on visual display, primarily through head-up display (HUD) or HMD. Concepts using auditory and haptic cueing for directional sensing have also been explored within these programs. On the basis of more than 50 years of development and refinement, HUDs are standard equipment in commercial aircraft, and HMDs are routinely used in fixed and rotary-wing military aircraft. Similar deployments do not exist for the dismounted soldier, although night vision enhancement goggles are routinely used, as these do not depend on digital infrastructures and linkages to weapons or operational equipment. In this section, we discuss selected aspects of the military and aviation programs that are pertinent to issues of situational awareness and attention for first responders.

The first documented design concept of an HMD was patented by Albert Pratt during World War I. This design, shown in Figure 12, was a sighting system for a helmet-mounted gun, which is "automatically aimed unconsciously to the turning of the head of the marksman in the direction of the target" (cited in Bayer, Rash & Brindle, 2009). Although this design was never implemented, the basic idea of "look and shoot" based on eye and head movement underlies contemporary HMDs.

Figure 12. Helmet-mounted targeting display concept of Albert Pratt.
(Source: Foote & Melzer, 2015)

7.1 Aviation

Practical application of superimposing task-relevant data upon the forward field of view was first accomplished in HUDs for aviation. Weapon target sighting was the basis for HUD development during World War II and later, by projecting an aiming symbol onto a semi-transparent mirror between the pilot and the windscreen (Prinzel & Risser, 2004). By the middle 1960s, HUDs were developed to show a synthetic runway outline; subsequent refinements led to standard HUD deployments in military and commercial aircraft. The theoretical advantage of HUD is that it reduces or eliminates eye movements away from the visual scene, and multiple pieces of task-relevant data can be presented simultaneously (Figure 13). Simulator studies indicate that pilots maintain flight path more accurately and can make better precision landings using HUD; additionally HUDs can enable landings in lower visibility, which reduces costs for airlines (Crawford & Neal, 2006).

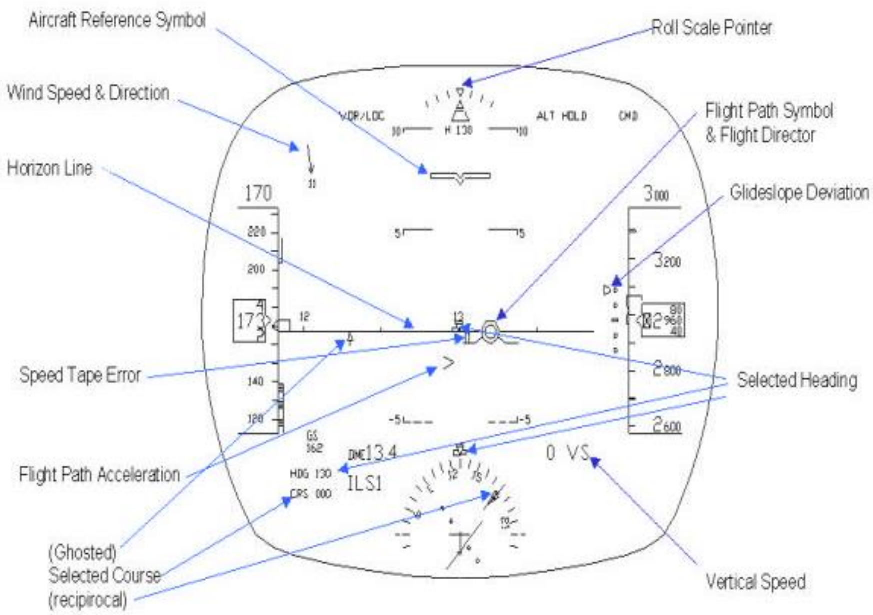

Figure 13. Typical HUD symbology.
(Source: Prinzell & Risser, 2004)

Military requirements for directing weaponry to off-boresight targets (i.e., off the main axis of the aircraft) have been the main driver for development of helmet-mounted displays, in both fixed and rotary-wing aircraft. In the United States, one of the earliest such HMDs was an electro-mechanical linkage that used a head-tracking system to direct the motion of a gimbal-mounted gun in the Cobra attack helicopter. Advances in missile weapon technology required a means of targeting that would allow G-forces beyond the limit of human endurance; visually coupled sighting allow the weapons to execute these rapid accelerations. The basic operation of HMDs is described by Bayer, Rash and Brindle (2009):

> Cueing HMDs make it possible to synthesize the target information by using an HMD with a cockpit computer and onboard advanced weapons' capabilities. Position sensors on the pilot's helmet track the instantaneous pilot's line-of-sight as it follows the target. The sensors relay critical information to the computer, which in turn, communicates the location of the target to the missile system. When the weapons lock onto the target, the pilot receives both audio and video signals, and then pulls the trigger located on the control stick to fire the missile. The advantage of the few extra seconds gained by getting the missile launch first, could well make the difference between life and death.

HMDs thus allow slaved weapon missiles to execute high G-force (more than 50 Gs) maneuvers in pursuit of a target, instead of the pilot, who can withstand 5-6G at most before loss of consciousness (Rash, et al., 2009, ch. 16). Many HMD systems have been developed for various platforms within the military. Figure 14 illustrates an HMD that is widely used in Navy and Air Force fighter aircraft.

Figure 14. The U.S. Air Force and Navy's Joint Helmet-Mounted Cueing System.
(Source: Foote & Melzer, 2015)

While the HMD shown in Figure 14 is very bulky and designed for aircraft operation *in-situ*, NASA is working toward designs that are more appropriately labeled "head-worn displays" (HWDs), as they employ a form factor that is equivalent to sunglasses (Figure 15), while providing transparent HUD overlays that vary with head position and have the potential to be operable across different aircraft platforms. Initial simulator experiments suggest that pilot performance with the smaller form factor HWDs is equivalent to that using a traditional HUD (Arthur, et al., 2015).

Figure 15. Prototype glasses form factor for commercial aviation HUD.
(Source: Arthur, et al., 2015).

7.2 Systems for Ground Forces

Enhancing the ability of ground forces to move, shoot, and communicate is the principal objective of an evolutionary series of Army programs starting in the late 1980s. Researchers at the Army Communications Electronics Command envisioned "a small wearable computer, integrated with a wireless link and helmet-mounted display (HMD)" (Zieniewicz, et al., 2002). This was first demonstrated as the Soldier's Computer (1990), followed by the Soldier Integrated Protective Ensemble (1990), Land Warrior (1994), Future Force Warrior (2005) and Nett Warrior (current), as well as other programs such as the DARPA Ultra-Vis (Figure 16). The initial envisioned capabilities of the Land Warrior system are very similar to the NGFR requirements for situational awareness (Zieniewicz, et al., 2002):

- Helmet-mounted display, audio and microphone
- Sensors for enhanced vision, targeting and aiming
- Stores and presents maps, mission data
- Maps provide graphical overlay of position and situation
- Soldier location, position reporting, target location
- Capability embedded within protective clothing ensemble

This long history of development across multiple programs has seen enhancements in virtually all technologies employed, and in constrained technical demonstrations certain performance advantages can be seen, such as reduced time in way-finding.

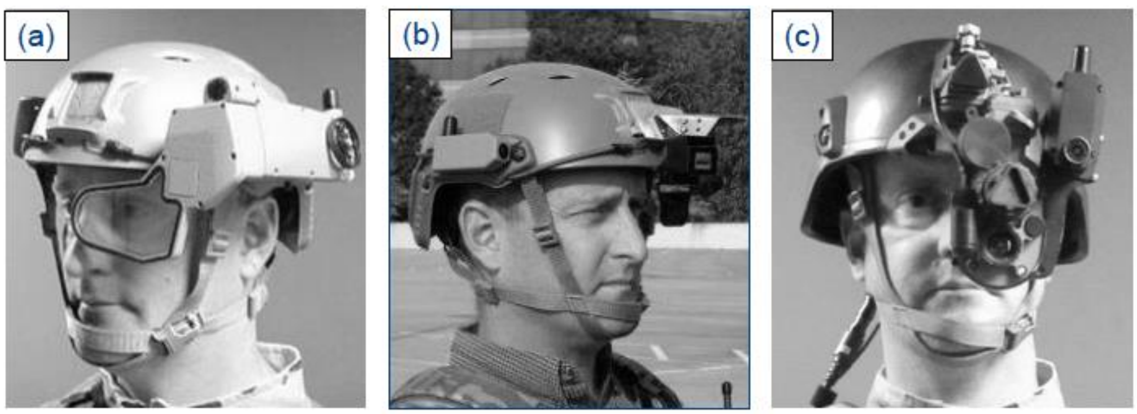

Figure 16. DARPA ULTRA-Vis helmet.
(a) DARPA ULTRA-Vis helmet kit with integrated ARC4 sensor components; (b) ARC4 railmounted head-tracking sensor decoupled mechanically from a see-through display; (c) ARC4 head-tracking sensor mounted to an enhanced night vision goggle (Source: Gans, et al., 2015)

Most of these programs focused on technical development and improvement as technology capability continues to advance. Limited field deployments have been conducted within operational units for testing purposes, generally to evaluate the capability of the technology. As with aviation HMDs, weight and comfort are critical issues, which continue to reduce user acceptance.

7.3 Human Factors Considerations

While aviation systems have reached the point of mature application, their development has been associated with increased understanding of human factors and attention issues that influence performance. HUDs have received considerable study by NASA and associated researchers, while HMDs have been addressed by the U.S. Army research laboratories. Both HUDs and HMDs have common issues that affect usability, task performance, and hence, situational awareness. A detailed discussion of these issues is beyond the scope of this report; a brief overview of the general issues is provided here.

HUD human factors design and implementation issues are reviewed by Crawford and Neal (2006). These include the following:

- Misaccommodation – This occurs when the eye is drawn to focus on something close, potentially impairing the ability to detect targets at greater focal distances. HUDs generally address this problem through *collimation* (i.e., aligning image elements to focus the eyes at optical infinity). Current research is unclear on the impact of collimation upon accommodation and performance impacts.
- Attentional capture – Evidence suggests that HUD elements can create an attentional focus on the display, impairing the ability to perceive aspects of the real-world view. For example, simulator studies have demonstrated reduced ability to detect runway incursions when HUD displays are in use.

These cognitive/perceptual issues interact with certain design elements, such as the type, location, density, and intensity (brightness) of symbology. While commercial HUDs provide de-cluttering capability, accident reports suggest that HUDs may occasionally be a contributing element to accidents.

HMDs are affected by the issues described above. Additionally, the following variables are important in HMD design:

- Weight – Most headsets used in aviation are light (12 to 18 oz). Display electronics can increase head-supported weight by 16 oz; military pilots wear HMDs that weigh over 4 lbs (Bayer, Rash & Brindle, 2009). This weight tends to be above and forward of the head's center of mass, and prolonged wearing of such an HMD can result in fatigue.
- Head/eye tracking and scene sensor latency – The head/eye tracking position needs to be relayed to external scene sensors so that they can be moved to the correct line-of-sight, acquire the scene, and transmit the imagery to the HMD. The latency or "slew rate" of the sensor moving to the new position needs to be less than 300 ms, or motion sickness may result.

It is clear from the discussion above that providing data via HUDs and HMDs is feasible in certain constrained circumstances, such as aviation, in which the human operator, external environment, and display electronics comprise an integral system. This is much more difficult in free-ranging situations, such as those encountered by dismounted soldiers or "boots-on-the-ground" first responders, although technologies continue to advance.

From the standpoint of human attention and situational awareness, the design variables and human performance impacts (real and potential) described above are similar to the circumstances associated with driver distraction. While there is a tendency among the engineering development community to interpret lack of negative feedback during technical demonstrations as confirming the value of HUDs and HMDs, this entails primarily anecdotal evidence. It is very much an open set of questions as to what to put on an HMD and where to locate it; current practice is guided by historical precedent more than precise human engineering guidelines (Newman & Haworth, 1994). These issues will be particularly important to address in the development of NGFR concepts and technologies for situational awareness, since first responders operate under high-stress conditions, which can further reduce attentional capabilities.

8.0 Wearables, Mobile Technology and Distraction – Other empirical studies

Thus far the discussion of technologies for situational awareness has been limited to traditional device models – cell phones, HMDS/HUDS, and in-vehicle computers for first responders. However, the “revolution in wearables” and the revived interest in augmented reality that is garnering so much media attention goes well beyond these “traditional” models of technology, to include glasses-like form factors, wrist-mounted displays and sensors, and fabric-based materials for bio-sensing and feedback. Additionally, the types of tasks we have considered so far have been limited to automobile driving and aircraft piloting. A limited number of studies have addressed a broader range of form factors and performance behaviors, which are reviewed in this section.

8.1 Visual Sensory Function Impairment

An important initial question regarding wearable and mobile technologies is the extent to which the device itself alters the sensory function of the human, such as the previously mentioned “phantom vibration” that is commonly reported by cell phone users. The trend toward embedding data feeds into HWDs, such as Google Glass prompts questions regarding how visual sensory function is affected by the form factor, independent of data feeds. To evaluate this question, Ianchulev, et al. (2014) tested the visual field function of users wearing Google Glass with the prism mounted as commonly worn, without any data feeds provided. Representative results are shown in Figure 17. The peripheral visual field is substantially reduced (Figure 17 b and d) for areas that are relatively less affected by the control glasses frame. These scotomas, or “blind spots,” are of concern in that peripheral vision is reduced and may degrade situational awareness.

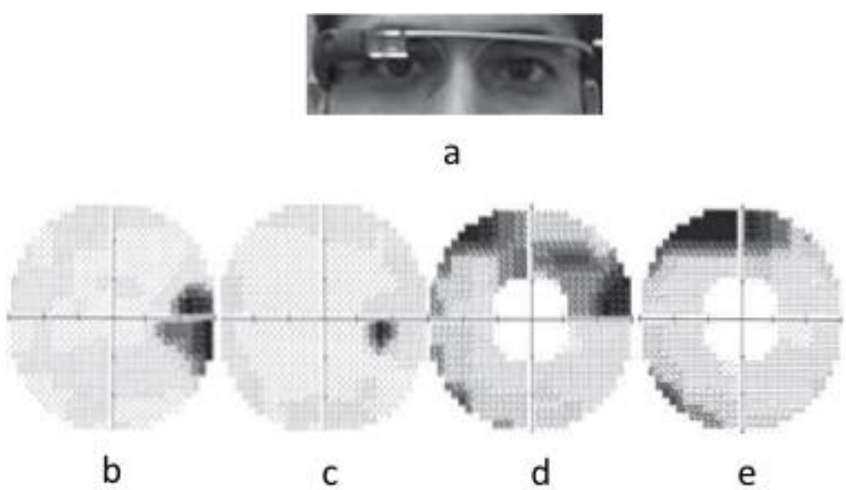

Figure 17. Effect of Google Glass on visual field function.
(a) location of glass prism, (b) 30° visual field with wearable device; (c) 30° visual field with control frame; (d) 60° visual field with wearable device; (e) 60° visual field with control frame. (Source: Ianchulev, et al., 2014)

Studies of Google Glass for messaging or destination entry while driving indicate that performance degradations are still observed (Sawyer, Finomore, Calvo & Hancock, 2014; He, Choi, McCarley, Chaparro & Wang, 205). This suggests that the combination of peripheral vision occlusion and distracting information and tasks leads to reductions in attention to safety-pertinent task elements.

8.2 Studies of Distraction in Doctors

Imagery enhancement has a long history of technical development and application in medicine. Surgeons must contend with many of the same factors of time criticality and uncertainty as first responders. While visualization devices such as endoscopes are routinely used, HWDs to facilitate visualization (beyond simple magnification and/or illumination) is an active area of research.

Several studies have addressed the role of augmented reality and HWDs relative to the attention and performance of physicians. Liu, et al. (2010) evaluated the use of an HWD for anesthesiologists during live cases and found that these physicians spent less time looking at monitoring equipment and more time looking at the patient, as the same data were displayed on the HWD. Distraction issues were not addressed, but there was considerable concern expressed regarding the weight and generally obtrusive nature of the equipment. Dixon, et al. (2013) evaluated the impact of augmented reality displays, provided on a stand-alone monitor, upon the ability of surgeons to detect foreign objects and severe anatomical complications in a series of images from a cadaver operation. Augmented reality (i.e., superimposing structural outlines on areas of interest) enhanced location finding, but detection of foreign objects and anatomical complications was severely degraded. A recent study by Mondal, et al. (2014) suggests that use of near-infrared contrast fluorescence in special goggles worn by a surgeon may enhance the ability to see the edges of tumors, thus improving surgical outcomes. In this case, the HWD provides the ability to visualize structures that cannot be seen unaided; the impact of the HWD on attention to other aspects of the surgery is unknown. This is a generally important concern, as the extent to which added visualization and cueing enhances detection of abnormalities that fit within the parameters of the visualization software may limit a more thorough search for non-conforming abnormalities (Berbaum, et al., 2007).

Mobile technologies such as smart phones and iPads are increasingly common in medical settings. Various advantages have been enumerated, including rapid order entry to a central medication systems, local/personal access to medical record information, imagery viewing, and time savings over workstation-based approaches (AHRQ, 2011). A survey study of smartphone usage during inpatient rounds at a New York academic hospital (Katz-Sidlow, et al., 2012) found that the majority of clinicians (residents, housestaff and faculty) use personal smartphones in their work. This survey also reported that more than 20% of the housestaff self-reported missing significant clinical information during rounds due to smartphone distraction. Further, observations of other staff suggest that the proportion may be even higher (as great as 40%). For example, interruptions from a text message received by a resident as he was entering a critical medication change order resulted in the order not being completed and subsequent adverse health consequences to the patient (AHRQ, 2011). The increasing trend in organizations is for a "bring your own device" policy, which reduces cost but provides connectivity benefits. However, interruptions from personal messages or calls in critical circumstances can have extremely adverse effects.

8.3 Distraction in Walking

Consider the following injury descriptions from the Consumer Product Safety Commission National Electronic Injury Surveillance System database (cited in Nasar & Troyer, 2013):

- "23 year old male walking on the middle line of the road talking on a cell phone and was struck by a car, contusion hip."
- "28 year old male walked into pole talking on phone and lacerated brow"
- "14 year old male walking down road talking on cell phone, fell 6–8 ft. off bridge into ditch with rocks and water, landed on chest/shoulder, chest wall contusion."

These descriptions are a sample of the types of injuries sustained by pedestrians resulting from cell phone conversations or texting while walking. A number of studies have now demonstrated that pedestrians show reduced situational awareness (e.g., inattention blindness for unusual or safety-pertinent items in the immediate environment) when they are engaged in cell phone usage. This is not necessarily related to being engaged in conversation, as situation awareness for strikingly odd occurrences (such as a unicycling clown) are noticed with greater frequency if people are talking together, compared with being alone or on a cell phone (Hyman, et al., 2010). Specific studies of street crossing safety indicate that pedestrians engaged in cell phone conversation cross more slowing and take greater risks in relation to oncoming vehicles (Nasar, Hecht & Wener, 2008). The Nasar and Troyer (2013) study shows that these types of behaviors and injuries have tripled since 2004, despite an overall *decrease* in other types of pedestrian injuries. Observational and video data suggest that engaging in cell phone conversations while walking changes the physical nature of how people walk, such that their gait is slower and more erratic (Hyman, et al., 2010; Perlmutter, et al., 2014). Observational studies of bicyclists have shown similar safety impairments as well, presumably due to degraded attention to the surrounding situation (Terzano, 2013).

9.0 Evaluation Studies of Wearables and Mobile Technologies for First Responders

There are no HMDs or HUDs currently available for first responder applications. While body cameras are becoming relatively common for law enforcement, and mobile phones are routinely used by all first responders, only a few studies have explored early prototype devices in simulated operational scenarios.

Several prototype HUDs have been tested in simulated firefighter navigation and training tasks. Wilson and Wright (2009) used a face-mask add-on display that was low-mounted and non-transparent. Way-finding was faster with the HMD, and numerous design issues were observed, including the need for a transparent display, ego-centric orientation (forward-up), and the time lag associated with the own-position reference. A prototype HMD with tactile belt alerts was evaluated by Streefker, Vos and Smets (2012), using a simulated victim-finding task. No performance enhancement with the HMD was observed; many subjects indicated feeling overloaded with information and distracted by some of the alerts. An external and body temperature HUD display was evaluated by the National Urban Security Technology (2013); numerous reliability issues were encountered with this prototype, and the ability to use post-hoc analysis software did not function.

Wearable cuff applications are envisioned for providing EMS services in single and multiple casualty events. A cuff display is meant to provide a map display of critical case location (based on prior triage), individual patient vital signs and local treatment history (and potentially, important medical record data), and an alerting function for patient status change requiring immediate attention. Numerous emergency medical technician (EMT) functional problems are addressed by this concept, including freeing the hands for patient handling, immediate visual access to important data, and the ability to record pertinent case information for communication to transport and receiving hospital.

NASA tested cuff display applications for supporting extra-vehicular activity in space operations, to replace "flip-book" checklists. While not in routine use, the experimental work indicates that organic light emitting diode displays can be incorporated into existing and planned spacesuit designs (Sarma, Schuck & Duke, 2010). Similarly, the Air Force is experimenting with cuff displays for battlefield information as a smaller alternative to tablets (Figure 18).

Figure 18. Wrist-mounted personal digital assistant.
(Source: Defense Tech, June 4, 2015)

Presently, cuff-mounted displays are in the earliest stages of testing, and it is evident from the picture in Figure 18 that further progress is required in miniaturization and flexibility.

Many ongoing research programs and product development efforts are in progress for flexible displays, as well as “pre-launch” announcements of flexible and/or wrist-mounted displays. As of this writing, the products announced in “pre-launch” press releases are not available for sale, and the companies involved appear to be small start-ups, some funded by crowd sourcing. Market interest notwithstanding, considerable work has been reported in the peer-reviewed scientific and engineering literature. Detailed reviews of thin-film electronics for emissive (Nathan, et al., 2012) and reflective displays (Heikenfeld, et al., 2011) clearly indicate progress toward enhanced readability and flexibility of materials. Substantial progress toward economically viable products would seem to depend on sufficient product demand for the materials science and manufacturing processes to be adapted in response to anticipated demand (Nathan, et al., 2012). Thus far, credible demonstrations are reported by Asian laboratories (Li, et al., 2015; Tajima, et al., 2015), and much of the discussion focuses on materials, integrated circuit, and power source manufacture.

Since flexible displays have not been linked directly to specific applications for widespread use, currently there is a poor understanding of how people would interact with them. The human-computer interaction research community has been actively exploring touch and gesture interactions with flexible computers. The general findings indicate that limiting interactions to scrolling, zooming, and position sensing precludes complexities associated with text input and editing, particularly with such a small surface (Schwesig, Poupyrev & Mori, 2004). Furthermore, there are certain gestural stereotypes that are regularly associated with navigation direction and page location re-positioning (Lahye, et al., 2011).

Currently, application of mobile technologies in EMS work is limited, other than mobile phones and/or public safety radio systems. While there is progress in wireless remote monitoring of select physiological variables, applications are still restricted to research environments or well-defined clinical settings. Intel and Oregon Health Sciences University (Wouhaybi, et al., 2013) report on an architecture study that integrated wireless patient monitoring, audio capture of EMT annotations, alarm processing algorithms, and a tablet display. The study is interesting more from the standpoint of design rather than specific results, in that the design team included substantial input from EMTs, and there was considerable focus on the need to ensure a smooth flow of patient-EMT interaction. Other evaluation studies of prototypes in simulated disaster scenarios suggest that electronic tools for triage (tablets, radiofrequency identification tags) provide a small (e.g., several second) advantage over paper-based methods (Case, et al., 2013). A field study of information technology use in Haiti (Levy, et al., 2010) suggests that generating patient identification at initial assessment on scene facilitates tracking through the entire medical system.

10.0 Summary, Conclusions and Research Path toward Design Guidelines

The research reviewed in this report provides a human-centered view of situational awareness, based on the limited capacities of people for processing information, which is determined largely on the basis of what they pay attention to at any particular moment. Attention can be consciously directed but also overridden by reflexive orienting mechanisms. Thus, ever-increasing levels of data that are streamed to people can have a beneficial impact in terms of speed and convenience of access, but also a detrimental impact on situational awareness. This is seen in social situations, driving, providing medical care, and even walking. First responders are subject to the same capacity limitations as civilian citizens; while they develop strategies and experience for what to pay attention to and when, it is clear from studies of emergency response driving and accidents that distraction and performance degradation occur as a result of technology.

Technology development has outpaced our understanding of how to design most appropriately for use by limited-capacity humans, partly because circumstances vary so considerably across applications. However, the general findings of technology-based distraction cannot be ignored, and the general guidance provided for attention-sensitive design represents a good starting point. The National Research Council (1997) provided such principles to help guide the design of soldier systems for situational awareness. These principles include the following:

> "1. The design of the display system should minimize the degree to which it is a physical barrier to acquiring environmental information (e.g., occludes or alters normal hearing and vision). It should enhance sensory input only when needed (e.g., targeting support, night vision).
>
> 2. The display design should minimize the degree to which it distracts attention (e.g., make the system removable, place it out of the normal line of sight).
>
> 3. The display design should minimize the cognitive load it places on the user by:
>
> - providing integrated information (e.g., fusing information from different sources),
> - providing easy user input of information (e.g., menus),
> - minimizing memory requirements,
> - reducing extraneous information,
> - simplifying the format of information presentation,
> - minimizing tasks,
> - presenting information in a task-oriented sequence and grouping, and
> - proving information in the needed format (e.g., egocentric maps).

4. The display should be designed to enhance situation awareness by providing salient cueing, directing attention to the most important information.

5. The display design should minimize complexity and avoid high levels of automation." (NRC, 1997, pp. 63-64).

Much more specific guidance for HMD design is provided by Melzer, et al. (2009). This work focuses on issues of visual design and physical ergonomics of helmet structure and is based on a long-standing program of research in the Army Research Laboratories. At the current stage of development for NGFR situational awareness technologies, most of these issues would be considerably downstream. However, more general design considerations associated with the most basic decisions, such as use of auditory versus visual presentation, can be used as a basis to develop design concepts for NGFR technologies. Deatherage (1972) formulated the basic issues (Table 2) in auditory versus visual presentation, and they are used frequently in the contemporary environment as well for addressing design questions concerning in-vehicle displays.

Table 2. Auditory versus visual forms of presentation (Deatherage, 1972).

Use auditory presentation if:	Use visual presentation if:
The message is simple (e.g., fire alarm).	The message is complex.
The message is short.	The message is long.
The message will not be referred to later (e.g., ambulance siren).	The message will be referred to later.
The message deals with events in time (e.g., telephone ring).	The message deals with location in space.
The message calls for immediate action (i.e., engine fire warning).	The message does not call for immediate action.
The visual system of the person is overburdened.	The auditory system of the person is overburdened.
The visual system is unavailable (e.g., receiving location is too bright or too dark; individual is asleep).	The receiving location is too noisy.
The person's tasks require him or her to move about continually.	The person's job allows him or her to remain in one position.
The origin of the signal itself is a sound (e.g., automobile horn).	

The research needs of the NGFR program for situational-awareness design guidance and parameters are quite similar to the recommendations provided 20 years ago to the Army by the National Research Council (1997). We adapted these recommendations to address what we believe to be the most pressing issues for designing attention-sensitive technologies for first responders. The research recommendations are:

1. Undertake research concerning the interaction between design attributes, human factors and effective performance in first responder jobs and tasks.
2. Develop catalogs of critical information needs for specific first responder tasks that can be provided by NGFR wearable and mobile technologies.
3. Develop realistic design concepts that incorporate near-term connectivity infrastructure (cellular, wireless, public safety radio, etc.) to develop field-testable prototype devices.
4. Determine threshold values for visual clutter in HMD and other wearables that incorporate displays, and design approaches to attention management such as de-cluttering.
5. Conduct research to evaluate the impact of high workload in emergencies upon attentional focus of responders – what do they pay attention to now, and how will additional data streams affect this?

6. Establish field research settings in which first responder situational awareness can be studied in a real-world context.

These research recommendations are provided as an initial step in what should be an iterative process of applied research into the human factors of first responder situational awareness, design and fabrication of testable prototypes, and evaluation of device and human performance in realistic settings.

11.0 References

Agency for Healthcare Research and Quality. (2011). Order Interrupted by Text: Multitasking Mishap https://psnet.ahrq.gov/webmm/case/257

Arsten, A.F.T., Berridge, C.W., & McCracken, J.T. The Neurological Basis of Attention-Deficit/Hyperactivity Disorder. *Primary Psychiatry*. 16(7): 2009.

Arthur, J.T., Bailer, R.E., Williams, S.P., Prinzel, L.J., Shelton, K.J., Jones, D.R., & Houston, V. (2015). A review of head-worn display research at NASA Langley Research Center. *Proceedings of the SPIE*. Vol. 9470: Display Technologies and Applications for Defense, Security and Avionics IX; and Head-and Helmet-Mounted Displays XX.

Baber, C., Smith, P., Cross, J., Zasikowski, D., & Hunter, J. (2005, October). Wearable technology for crime scene investigation. In *Wearable Computers, 2005. Proceedings. Ninth IEEE International Symposium on* (pp. 138-141). IEEE.

Bayer, M.M., Rash, C.E., & Brindle, J.H. (2009). Introduction to Helmet-Mounted Displays. In Rash CE, Russo, MB, Letowski, TR and Schmeisser, ET. *Helmet-Mounted Displays: Sensation Perception and Cognition Issues.* Fort Rucker, AL: US Army Aeromedical Research Laboratory. pp. 47 – 108.

Berbaum, K.S., Caldwell, R.T., Schartz, K.M., Thompson, B.H., & Franken, E.A. (2007). Does Computer-Aided Diagnosis for Lung Tumors Change Satisfaction of Search in Chest Radiography? *Academic Radiology*. 14(9): 1069 – 1078.

Bopp, K. (2012). Attention! (Specifically, Selective Attention). http://webs.wofford.edu/boppkl/courseFiles/Cognition/CogPPT10_files/4_SelectAttention_auditory_pt2.pdf

Broadbent, D. (1958). *Perception and Communication*.

Brown, I.D., Tickner, A.H., & Simmonds, D.V. (1969). Interference between concurrent tasks of driving and telephoning. *Journal of Applied Psychology*. 53(5): 419 – 424.

Byrne, E. (2015). Commentary on Endsley's "Situation Awareness Misconceptions and Misunderstandings." *Journal of Cognitive Engineering and Decision Making*. 9(1) 84 – 86.

Case, T., Morrison, C., & Vuylsteke, A. (2012). The clinical application of mobile technology to disaster medicine. *Prehospital and Disaster Medicine.* 27(5): 473 – 480.

Charlton, S.G. (2009). Driving while conversing: Cell phones that distract and passengers who react. *Accident Analysis and Prevention*. 41: 160 – 173.

Crawford, J. & Neal, A. (2006). A review of the perceptual and cognitive issues associated with the use of head-up displays in commercial aviation. *International Journal of Aviation Psychology*. 16(1): 1-19.

Croskerry, P. (2002). Achieving quality in clinical decision making: cognitive strategies and detection of bias. *Academic Emergency Medicine, 9*(11), 1184-1204.

Deatherage, B.H. (1972). Auditory and other sensory forms of information presentation. In: van Cott, H.P., and Kinkade, R.G. (Eds.), Human Engineering Guide to Equipment Design. Washington, DC: Government Printing Office.

Department of Homeland Security (2015). Envisioning the Next Generation First Responder. http://www.firstresponder.gov/Pages/Envisioning-the-Next-Generation-First-Responder.aspx.

Department of Homeland Security. (2014). Project Responder 4. http://www.firstresponder.gov/TechnologyDocuments/Project%20Responder%204.pdf.

Dixon, B.J., Daly, M.J., Chan, H., Vescan, A.D., Witterick, I.J., & Irish, J.C. (2013). Surgeons blinded by enhanced navigation: the effect of augmented reality on attention. *Surgical Endoscopy*. 27: 454 – 461.

Endsley, M.R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*. 37(1): 32 – 64.

Endsley, M.R. (2000). Theoretical underpinnings of situation awareness: A critical review. In Endsely, MR and Garland, DJ (Eds.). *Situation Awareness Analysis and Measurement*. Mahwah, NJ: Lawrence Earlbaum Associates.

Flanagan, J.C. (1954). The critical incident technique. *Psychological Bulletin*. 51(4): 327 – 358.

Fern, L.C., (2008). *Coordination in urban firefighting: a critical incident analysis.* Unpublished master's thesis, The Ohio State University, Columbus, OH

Fern, L., Trent, S., & Voshell, M. (2008). A functional goal decomposition of urban firefighting. *Proceedings of the 5th International ISCRAM Conference*, Washington, D.C.

Foote, B. & Melzer, J. (2015). A history of helmet mounted displays. *Proceedings of the SPIE*. Vol. 9470: Display Technologies and Applications for Defense, Security and Avionics IX; and Head-and Helmet-Mounted Displays XX.

Frye, L.M., & Wearing, A.J. (2014). What were they thinking? A model of metacognition for bushfire fighters. *Human Factors Challenges in Emergency Management: Enhancing Individual and Team Performance in Fire and Emergency Services*, 57.

Gans, E., Roberts, D., Bennet, M., Towles, H., Menozzi, A., Cook, J., & Sherrill, T. (2015). Augmented reality technology for day/night situational awareness for the dismounted Soldier. *Proceedings of the SPIE.* Vol. 9470: Display Technologies and Applications for Defense, Security and Avionics IX; and Head-and Helmet-Mounted Displays XX.

Governors Highway Safety Association. (2015). Distracted driving laws. Retrieved from http://www.ghsa.org/html/stateinfo/laws/cellphone_laws.html

Hagiwara, M.A. (2014). Development and Evaluation of a Computerised Decision Support System for use in pre-hospital care. Dissertaion Series No. 52, School of Health Sciencs, Jönköping University, Jönköping, Sweden.

Hayhoe, M. (2010). Eye Movements and Action in Everyday Life. In EB Goldstein (Ed.). *Encyclopedia of Perception*. Sage Publishing. http://knowledge.sagepub.com.offcampus.lib.washington.edu/view/perception/SAGE.xml

He, J., Choi, W., McCarley, J.S., Chaparro, B.S., & Wang, C. (2015) Texting while driving using Google Glass™: Promising but not distraction-free. *Accident Analysis and Prevention*. 81: 218 – 229.

Heikenfeld, J., Drzaic, P., Yeo, J.S., and Koch, T. (2011). A critical review of the present and future prospects for electronic paper. *Journal of the SID*. 19(2): 129 – 156.

Helsen, W.F., & Starkes, J. L. (1999). A new training approach to complex decision making for police officers in potentially dangerous interventions. *Journal of Criminal Justice, 27*(5), 395 – 410.

Hernandez-Peon, R., Scherrer, H., & Jouvet, M. (1956). Modification of electric activity in cochlear nuclear during attention in unanesthetized cats. *Science*. 123: 331 – 332.

Horrey, W.J. & Wickens, C.D. (2006). Examining the impact of cell phone conversations on driving using meta-analytic techniques. *Human Factors*. 48(1): 196 – 205.

Horrey, W.J., Lesch, M.F., & Garabet, A. (2008). Assessing the awareness of performance decrements in distracted drivers. *Accident Analysis and Prevention*. 40: 675 – 682.

Hyman, I.E., Boss, S.M., Wise, B.M., McKensie, K.A., & Caggiano, J.M. (2010). Did you see the unicycling clown? Inattentional blindness while walking and talking on a cell phone. *Applied Cognitive Psychology*. 24: 597 – 607.

Ianchulev, T., Minckler, D.S., Hoskins, H.D., Packer, M., Stamper, R., Pamnani, R.D., & Koo, E.Y. (2014). Wearable technology with head-mounted displasy and visual function. *JAMA*. 312(17): 1799 – 1801.

International Fire Service Training Association (IFSTA). (2013). *Essentials of Fire Fighting and Fire Department Operations.* Upper Saddle River, NJ: Brady Publishing.

James, S.M. (2015). Distracted driving impairs police patrol officer driving performance. *Policing: An International Journal of Police Strategies and Management*. 38(3): 505 – 516.

Jensen, J.L. (2011). Paramedic clinical decision-making: result of two Canadian studies. *Journal of Paramedic Practice*, *1*(2), 63 – 71.

Johnson, J.G., & Raab, M. (2003). Take the first: Option-generation and resulting choices. *Organizational Behavior and Human Decision Processes*, *91*(2), 215 – 229.

Kantowitz, B.H. (1983). *Human Factors: Understanding People-System Relationships*. New York: Wiley.

Karlin, J.E. (2003). The Establishment of HFT and the Early History of Human Factors in the Telecommunication Industry. http://www.hft.org/HFT03/paper03/00_Karlin.pdf. Accessed October 8, 2015.

Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Kahneman, D. (2011). *Thinking Fast and Slow*. New York: Farrar, Strauss and Giroux.

Katz-Sidlow, R.J., Ludwig, A., Miller, S., & Sidlow, R. (2012). Smartphone use during inpatient attending rounds: Prevalence, patterns, and potential for distraction. *Journal of Hospital Medicine*. 7(8): 595 – 599.

Klein, G.A., Calderwood, R., & Clinton-Ciroicco, A. (1986). Rapid decision making on the fire ground. In *Proceedings of the Human Factors Society 30th Annual Meeting*. Santa Monica, CA: Human Factors Society. pp. 576 – 580.

Klein, G., Wolf, S., Militello, L., & Zsambok, C. (1995). Characteristics of skilled option generation in chess. *Organizational Behavior and Human Decision Processes*, *62*(1), 63 – 69.

Klein, G.A. (2008). Naturalistic decision making. *Human Factors*. 50(3): 456 – 460.

Kowler, E. (2011). Eye movements: The past 25 years. *Vision Research*. 51: 1457 – 1483.

Lahey, B., Girouard, A., Burleson, W., & Vertegaal, R. (2011). PaperPhone: Understanding the use of bend gestures in mobile devices with flexible electronic paper displays. *Computer-Human Interaction 2011*. Vancouver, BC, pp. 1303 – 1312.

Leven, D.T., Momen, N., Drivdahl, S.B., & Simons, D.J. (2000). Change blindness blindness: The metacognitive error of overestimating change-detection ability. *Visual Cognition*. 7: 397 – 412.

Levy, G., Blumberg, N., Kreiss, Y., Ash, N., & Merin, O. (2010). Application of information technology within a field hospital deployment following the January 2010 Haiti earthquake disaster. *Journal of the American Medical Informatics Association*. 17: 626 – 630.

Li, W.Y., Chiu, P.H., Huan, T.H., Lu, J.K., et al. (2015). Thre first flexible liquid crystal display applied for wearable smart device. *SID Digest*. 9.3: 98 – 101.

Lin, Y.-H., Lin, S.-H., Li, P., Huang, W.-L., & Chen, C.-Y. (2013). Prevalent hallucinations during medical internships: Phantom vibration and ringing syndromes. *PloS One*, 8(6), Article e65152.

Liu, D., Jenkins, S.A., Sanderson, P.M., Fabian, P., & Russell, J. (2010). Monitoring with Head-Mounted Displays in General Anesthesia: A Clinical Evaluation in the Operating Room. *Anesthisa and Analgesia*. 2010, 110(4): 1032 – 1038.

Lipshitz, R., Omodei, M., McLennan, J., & Wearing, A. (2007) What's burning? The RAWFS heuristic on the fire ground. In R. Hoffman (Ed.), *Expertise out of context: Proceedings of the sixth international conference on naturalistic decision making* (pp. 97–111). New York, NY: Lawrence Erlbaum.

Magoun, H.W. (1963) *The Waking Brain*. Springfield, IL: Charles C. Thomas.

McKnight, A.J. & McKnight, A.S. (1993). The effect of cellular phone use upon driver attention. *Accident Analysis and Prevention*. 25(3): 259 – 265.

Melzer, J.E., Brozoski, F.T., Letowski, T.R., Harding, T.H., & Rash, C.E. (2009). Guidelines for HMD design. In Rash CE, Russo, MB, Letowski, TR and Schmeisser, ET. *Helmet-Mounted Displays: Sensation Perception and Cognition Issues.* Fort Rucker, AL: US Army Aeromedical Research Laboratory. pp. 805 – 848.

Misra, S., Cheng, L., Genevie, J., & Yuan, M. (2014). The iPhone Effect: The Quality of In-Person Social Interactions in the Presence of Mobile Devices. *Environment and Behavior*. July: 1-24.

Mondal, S.B., Gao, S., Zhu, N., Liu, Y., Sudlow, G.P., Akers, W.J., Liang, R., Gruev, V., & Achilefu, S. (2014). Intraoperative imaging and fluorescence image guidance in oncologic surgery using a wearable fluorescence goggle system. *Proceedings of SPIE: Design and Quality for Biomedical Technologies VII.*

Nasar, J., Hecht, P., & Wner, R. (2008). Mobile telephones, distracted attention, and pedestrian safety. *Accident Analysis and Prevention*. 40: 69 – 75.

Nasar, J.L. & Troyer, D. (2013). Pedestrian injuries due to mobile phone use in public places. *Accident Analysis and Prevention*. 57: 91 – 95.

National Safety Council. (2012). Understanding the Distracted Brain: Why Driving While Using Hands-Free Cell Phones is Risky Behavior. White Paper, April.

Newman, R.L. & Haworth, L.A. (1994). Helmet-Mounted Display Requirements: Just Another HUD or a Different Animal Altogether? *Proceedings of the SPIE*. Vol. 2218.

Norman, D. (2013). The Paradox of Wearable Technologies. *MIT Technology Review*. July 24.

Nathan, A., Ahnood, A., Cole, M.T., Lee, S., et al. (2012). Flexible electronics: the next ubiquitous platform. *Proceedings of the IEEE.* 100 (May 13): 1486 – 1517.

National Urban Security Technology Laboratory (2013). Test Report for the Internal/External Temperature Heads-Up Display. N-TB-TR-13-0001.

Parasuraman, R. & Galster, S. (2013) Sensing, assessing, and augmenting threat detection: behavioral, neuroimaging, and brain stimulation evidence for the critical role of attention. *Frontiers in Human Neuroscience*. 7: Article 273, pp. 1 – 10.

Perlmutter, S., Cades, D.M., Heller, M.F., Giachetti, R., Arndt, S.R., & Sala, J.B. (2014). Effects of mobile technology use on walking. *Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting.* pp. 2166 – 2170.

Peterson, S.E. & Posner, M.I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*. 35: 73 – 89.

Posner, M.I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*. 32: 3 – 25.

Prinzel, L.J. & Risser, M. (2004). Head-up Displays and Attention Capture. NASA/TM-2004-213000.

Przyblski, A. & Weinstein, N. (2012). Can you connect with me now? How the presence of mobile communication technology influences face-to-face conversation quality. *Journal of Social and Personal Relationships.* 30(3): 237 – 246.

Rash, C.E., Hiatt, K.L., Wildzunas, R.M., Caldwell, J.L., Caldwell, J.A., Kalich, M.E., Lang, G.T., King, R.P., & Noback, R. (2009). Performance effects due to adverse operational factors. In Rash CE, Russo, MB, Letowski, TR and Schmeisser, ET. *Helmet-Mounted Displays: Sensation Perception and Cognition Issues.* Fort Rucker, AL: US Army Aeromedical Research Laboratory. pp. 675 – 804.

Randel, J. M., Pugh, H. L., & Reed, S. K. (1996). Differences in expert and novice situation awareness in naturalistic decision making. *International Journal of Human-Computer Studies, 45*(5), 579-597.

Reed, M.P. & Green P.A. (1999). Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialing task. *Ergonomics*. 42(8): 1015 – 1037.

Regan, M.A., Hallett, C.C., & Gordon, C.P. (2011). Driver distraction and driver inattention: Definition, relationship and taxonomy. *Accident Analysis and Prevention*. 43: 1771 – 1781.

Sasse, M. A., & Johnson, C. (1999, December). A wearable computer for paramedics: Studies in model-based, user-centred and industrial design. In *Human-computer Interaction, INTERACT'99: IFIP TC. 13 International Conference on Human-Computer Interaction, 30th August-3rd September 1999, Edinburgh, UK* (Vol. 1, p. 126). IOS Press.

Sarma, K., Schuck, D., & Duke, D. (2010). The past present and future of display technology in space. AIAA SPACE 2010 Conference and Exposition, AIAA 2010-8195.

Sawyer, BD, Finomore, VS, Calvo, AA and Hancock, PA. (2014). Google Glass: A driver distraction cause or cure? *Human Factors*. 56(7): 1307 – 1321.

Schwesig, C., Poupyrev, I., & Mori, E. (2004). Gummi: A bendable computer. *Computer-Human Interaction 2004*. Viennea, Austria.

Simon, H.A. (1992). What is an explanation of behavior? *Psychological Science*. 3: 150 – 161.

Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: sustained inattentional blindness for dynamic events. Perception, 28, 1059-1074.

Smith, M. W., Bentley, M. A., Fernandez, A. R., Gibson, G., Schweikhart, S. B., & Woods, D. D. (2013). Performance of experienced versus less experienced paramedics in managing challenging scenarios: a cognitive task analysis study. *Annals of emergency medicine*, *62*(4), 367-379.

Stanners, M., & French, H. T. (2005). *An empirical study of the relationship between situation awareness and decision making* (No. DSTO-TR-1687). Defence Science and Technology Organization, Edinburgh (Australia), Land Operations Div.

Strayer, D.L. (2015). Is the technology in your car driving you to distraction? *Policy Insights from the Behavioral and Brain Sciences*. 1 – 9.

Strayer, D.L., Drews, F.A., & Crouch, D.J. (2006) A compasions of the cell phone driver and the drunk driver. *Human Factors*. 48(2): 381 – 391.

Strayer, D.L., Cooper, J.M., Turrill, J., Coleman, J., Medeiros-Ward, N., & Biondi, F. (2013). *Measuring Cognitive Distraction in the Automobile*. Washington, DC: AAA Foundation of Traffic Safety.

Streefker, J.W., Vos, W., & Smets, N. (2012). Evaluating a multimodal interface for firefighting rescue tasks. *Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting*. 277 – 281.

Stothart, C., Mitchum, A., & Yehnert, C. (2015). The attentional cost or receiving a cell phone notification. *Journal of Experimental Psychology: Human Perception and Performance*. 41(4): 893 - 97.

Tajima, R., Miwa, T., Oguni, T., Hitotsuyanagi, A., et al. (2015). Truly wearable display comprised of a flexible battery, flexible display panel, and flexible printed circuit. *Journal of the SID*. 22(5): 237 – 244.

Terpak, M.A. (2002). *Fireground Size-up*. Tulsa, OK: PennWell Corporation.

Terzano, K. (2013). Bicycling safety and distracted behavior in The Hague, the Netherlands. *Accident Analysis and Prevention*. 57: 87 – 90.

Tison, J., Chaudhary, N., & Cosgove, L. (2011). National Phone Survey on Distracted Driving Attitudes and Behaviors. Report No. DOT HS 811 555. National Highway Traffic Safety Administration, Office of Behavioral Safety Research.

Upton, J. F., & Stein, S. L. (2015). *Responder Technology Alert Monthly (January 2015)* (No. PNNL-24104). Pacific Northwest National Laboratory (PNNL), Richland, WA (US).

Uttaro, M. T. (2002*). Naturalistic Decision Making in Law Enforcement Practice - Exploring the Process*. Unpublished Dissertation, Virginia Polytechnic Institute and State University, Blacksburg.

Wang, J.S., Knipling, R.R. & Goodman, M.J. (1996). The role of driver inattention in crashes: New statistics from the 1995 Crashworthiness Data System. *Proceedings of the 40th Annual Association for the Advancement of Automotive Medicine*.

Wickens, C.D. (1984). *Engineering Psychology and Human Performance*. Columbus, OH: Charles E. Merrill Publishing Company.

Wickens, C.D. & McCarley, J.S. (2008). *Applied Attention Theory*. New York: CRC Press.

Wilson, J., Steingart, D., Romero, R., Reynolds, J., Mellers, E., Redfern, A., Lim, L., Watts, W., Patton, C., Baker, J., & Wright, P. Design of monocular head-mounted displays for increased indoor firefighting safety and efficiency. In *Defense and Security* (pp. 103-114). International Society for Optics and Photonics.

Wilson, J., & Wright, P. (2007). Design of monocular head-mounted displays, with a case study on fire-fighting. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *221*(12), 1729 – 1743.

Wilson, J., & Wright, P. (2009). Head-mounted display efficacy study to aid first responder indoor navigation. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*. 223: 675 – 688.

Woodworth, R.S. (1938). *Experimental Psychology*. New York: Henry Holt and Company.

Wouhaybi, R.H., Yarvis, M.D., Sharma, S., Muse, P., Wan, C.Y., Prasad, S., Durham, L., Sahni, R., Norton, R., Curry, M., Jimison, H., Harper, R., & Lowe, R.A. (2013). Experiences with context management in emergency medicine. *ACM Transactions on Embedded Computing Systems*. 12(4): 100:1 – 100:22.

Wyatt, A. (2012). Paramedic practice–knowledge invested in action. *Australasian Journal of Paramedicine, 1*(3), 9.

Yager, C., Dinakar, S., Sanagaram, M., & Ferris, T.K. (2015). Emergency Vehicle Operator On-Board Device Distractions. Texas A&M Transportation Institute Technical Report.

Zieniewicz, M.J., Johnson, D.C., Wong, D.C., & Flatt, J.D. (2002). The evolution of Army wearable computers. *Pervasive Computing*. October/December, pp. 30 – 40.

Zsambok, C.E. & Klein, G. (1997). Naturalistic Decision Making. Malwah, NJ: Lawrence Earlbaum Associates.

Zimmerman, L.A. (2008). Making Sense of Human Behavior: Explaining How Police Officers Assess Danger During Traffic Stops. In J. M. Schraagen, L. G. Militello, T. Ormerod, & R. Lipshitz (Eds.), *Naturalistic decision making and macrocognition* (pp. 121-140). Aldershot, England: Ashgate.

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